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Status of biodiesel research and development in Pakistan

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A B S T R A C T

Performance of biodiesel in engines is well established and biodiesel is currently adjudged as a low carbon fuel with the most potential of replacing fossil fuels. The fossil fuel sources are dwindling in Pakistan resulting in importation of about 8.1 million tonnes at approximately US$ 9.4 billion per annum. In the ambit of this justification, augmenting the energy scarce resources in Pakistan through intense harnessing of the varied biodiesel sources can adequately address the deficiency and can ensure energy security. Towards this end, the progress attained in biodiesel related researches in Pakistan are evaluated and presented with the view of highlighting ways of achieving the target set by the Government. A feedstock that drew less attention is spent triglycerides, and the little work reported by some organizations appeared promising. Now the onus is upon organizations such as the Alternative Energy Development Board and Pakistan State Oil to harness the research results from several indigenous Universities and develop a full-scale biodiesel economy in Pakistan.

Contents

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1. Introduction

Pakistan, despite being an agricultural country with approximately 45.2 million hectares of marginal land in the provinces of Sind & Punjab [1,2], is having a deficiency in the energy sector and the current population of 176.4 million in 2011 [1] have resulted in tighter supply that vividly suggests the growing energy demand cannot be met adequately.

The major energy challenges the country faces can be classified as sustainability, security of supply, safety of the energy chain and growing demand [3]. It has been suggested by several local scientists that biodiesel can be produced from the inedible crops grown on this marginal land and employment can be created for the poor farmers as a positive side effect [4–6]. The vegetable oil is expelled from the seeds and the oil cake can be used as fodder for livestock. On the other hand, the oilseed residues can be composted (bio fertilizer can be produced—nitrogen, phosphorus and potassium rich) and it can be used to produce energy by means of methane gas for power generation [5,6].

This fact can come as welcome news to a nation that has limited reserves of fossil fuels [6]. Already Pakistan is heavily dependent on crude oil as an energy source and during fiscal year 2008/2009, about 8.1 million tonnes was imported [7]. This and the import of other energy sources have led to a staggering import bill of US$ 9.4 billion in the same fiscal year. Thus the Government of Pakistan has laid down various schemes to harness indigenous renewable sources of energy, amongst which, biodiesel [8], solar and wind [9] may have a big role to play. However, real data from Pakistani institutes, universities and industry are not previously reported. For instance, Khan and Dessouky [6] discussed the current ailing energy scenario in Pakistan and suggested how biodiesel harnessed from indigenous vegetation could solve the problem; still such data from commercial and University research ventures was not presented. In other words, the authors described the general properties of biodiesel at length but did not go in depth about the progress of biodiesel research initiatives that have been undertaken during the last decade in Pakistan.

Therefore, this paper reviews the current status of biodiesel research and development being implemented in Pakistan and suggestions are put forth to ensure an effective contribution from various organizations to meet important targets set by the Government of Pakistan. The data was generated by conducting a general online search for published articles with specific interest on the institutes/universities reporting researches on biodiesel. In addition personal communication with some colleagues in the Pakistani Institutes helped consolidate the work. Furthermore, the possibility of harnessing spent triglycerides (vegetable oil and animal fat) for the production of biodiesel in Pakistanis discussed.

2. Biodiesel from transesterification reaction

The literature is replete with several review papers on the transesterification process but basically it involves three reversible reactions, whereby the triglyceride is converted successively to diglyceride, monoglyceride and glycerol, consuming one mole of alcohol in each step and liberating one mole of ester [10–12]. A schematic representation of the transesterification reaction is shown in Fig. 1 [12]. The final biodiesel composition depends on the initial feedstock, as well as on the reaction conversions and process separation efficiencies. The thermo-physical properties depend upon factors such as chain length, branching, and degree of saturation [13]. Transesterification can occur using either homogeneous or heterogeneous catalysts, for example, heteropolyacids supported over clay [11]. When the raw materials (oils or fats) have a high percentage of free fatty acids or water, the alkali catalyst will react with the free fatty acids to form soaps. The water can hydrolyze the triglycerides into diglycerides and form more free fatty acids. Both of the above reactions are undesirable and reduce the yield of the biodiesel product. In this situation, the acidic materials should be pre-treated to inhibit the saponification reaction [14].

3. Prospects of biodiesel for Pakistan's economy

An economic analysis for indigenous oils in Spain showed that the main factor in the high price of biodiesel in comparison to mineral diesel is due to the virgin vegetable oil [15]. Other economic studies also proved the same [16–19] and the only way round this problem seemed to be in the harnessing of vegetable oil from indigenous vegetation that could grow on marginal land [20,21]. This is where India successfully exploited the jatropha plant to produce and consume low cost biodiesel fuel in the past decade [20,21]. Other countries have also tried to explore microalgae as feedstock for biodiesel production and achieved some success [22,23]. However, Pakistan appeared to remain behind the scenes in a global biodiesel game.

Pakistan's present total primary energy demand is estimated to be around 32 MTOE (million tons of oil equivalent) whereas the total primary energy supply is around 63 MTOE [24,25]. Although there appears to be a surplus of energy, it has to be noted that most of it is imported and not of indigenous origin (thereby labeling the country as being energy deficient). In addition, the consumption pattern is ever increasing (at a rate of about 5% per annum) and is likely to outrun supply in the long term [26]. The major energy consumption sectors of Pakistan are domestic, commercial, industrial, agricultural, transport and other government sectors [25]. For sustainable economic growth, continuous and cheap supply of energy is necessary [27]. At present, the role of renewable and sustainable sources of energy in Pakistan is meager to say the least [28] and major efforts are required to make it a significant player in the country's energy supply mix [29].

There are recent published research papers highlighting the prospects of biodiesel for Pakistan [6,30]. In it Pakistan's present energy scenario has been critically discussed and the possibility of biodiesel being produced on large scale is also elaborated. It is

$$
\begin{array}{lcccccc}
\mathrm{CH_2{-}O{-}CO{-}R_1} & & & & \mathrm{CH_2{-}OH} & & \mathrm{R{-}O{-}CO{-}R_1} \\
\mathrm{CH{-}O{-}CO{-}R_2} & + & \mathrm{3ROH} & \xrightarrow{\text{(Catalyst)}} & \mathrm{CH{-}OH} & + & \mathrm{R{-}O{-}CO{-}R_2} \\
\mathrm{CH_2{-}O{-}CO{-}R_3} & & & & \mathrm{CH_2{-}OH} & & \mathrm{R{-}O{-}CO{-}R_3} \\
\text{(Triglyceride)} & & \text{(Alcohol)} & & \text{(Glycerol)} & & \text{(Mixture of fatty acid esters)}
\end{array}
$$

Fig. 1. Schematic representation of transesterification reaction [12].

emphasized that the production of biodiesel is required for sustainable development and to reduce dependency on imported fuel. That is because according to the report of the Oil Companies Advisory Committee (OCAC) 2008, Pakistan was consuming around 8 million tons of diesel and 7.2 million tons of furnace oil per year [6]. Yet, Pakistan is considered as a low green house gas emitting country contributing 0.43% of the world's total emissions.

The main conclusion that was drawn from the study reported in the paper was that if indigenous vegetation yielding inedible oil is grown on vast barren areas of the country, the feedstock cost could be reduced and biodiesel could become a positive solution to Pakistan's ailing energy economy [6]. In addition, some parts of the marginal land could be used to develop engineered ponds for algal growth for biodiesel production.

About 70% of Pakistan's total geographical area of 80 million ha lies uncultivated, thereby giving opportunities for growing biodiesel yielding vegetation [31]. Among them are *Brassica campestris* (Mustard) with oil yield of 33%, *Eruca sativa* (taramira or bitter mustard) with oil yield of 35% [32] and *Ricinus communis* (castor bean) with oil yield of 32% [4]. Due to the vast area and varied agro climatic conditions of Pakistan, the land mass will support the cultivation of these and many other crops. A summary of various oil bearing vegetation, their respective oil yield and fatty acid content is given in Table 1. Thus it is the need of the hour to develop plant based biodiesel industries in Pakistan, which will be useful for the future by improving socio-economic conditions of the country [33].

This review attempts to describe various research efforts underway in several Universities and industries in Pakistan for harnessing of indigenous vegetation for biodiesel production. The Government of Pakistan created the Alternative Energy Development Board (AEDB) with this specific mission and one of the important scope of work (as laid down by the Economic Coordination Committee) included the employment of at least 10% biodiesel in the diesel fuel market of Pakistan by the year 2025 [8]. If this target could be achieved then the country may be able to earn a saving of US$ 1 billion per year by cutting imports of expensive fossil fuels [29].

4. Research and development on biodiesel in various Pakistani institutions

Various projects have been conducted at different universities and industries in Pakistan. However, all efforts were conducted at individual scales and there appeared to be little sharing of knowledge between institutions. This work may be the first attempt at compiling all the data generated by several indigenous institutions and presenting the work in a coherent form for the benefit of the future research community.

4.1. *Impact of jatropha and pongame on Pakistan's biodiesel plans*

Pakistan's effort in rearing and harnessing jatropha and pongame plants for biodiesel production is nothing short of praiseworthy. Research and development is currently underway and are reviewed in this section.

4.1.1. *Status of jatropha cultivation for biodiesel production*

The existence of jatropha has been reported in the Sindh province since long [36]. It was and is still known as Karanga, RatanJoth or Jamal Ghota and was used for various ailments in the villages and towns [37]. At present only two plants have survived and are located near Umerkot. These plants are more than 40 years old and have attained a height of 30 ft. This suggests that the jatropha may have been in Pakistan before its independence [36].

Jatropha has been mainly cultivated through imported seeds from several countries by private entrepreneurs at the micro scale [36]. However, despite such private sector efforts, their cultivation has risen from around 2 acres in 2005 to more than 400 acres in 2008 as shown in Fig. 2. This surge in jatropha cultivation was mainly because of an aggressive campaign undertaken by the Alternative Energy Development Board (AEDB) [8,36].

In the private sector quite a number of institutions have been growing jatropha nurseries at various sites in Sindh, Punjab and Balochistan. These nurseries have become the basis for a number of jatropha farms in the same regions. Plants have an average age between several weeks to more than 18 months in these farms [36].

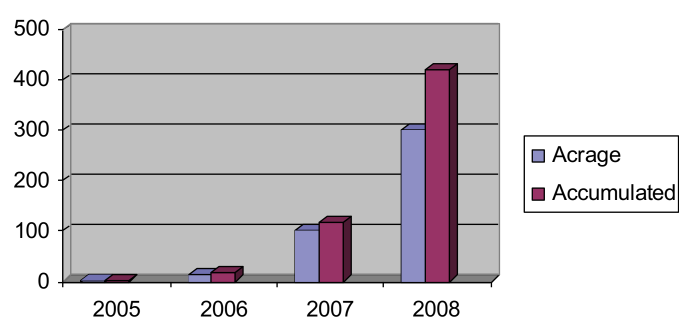

Fig. 2. Statistical growth of jatropha cultivation in Pakistan [36].

Table 1
Summary of indigenous oil-bearing vegetation in Pakistan and their fatty acid profile.

No.	Seed	Oil Yield (%)	14:0	16:0	18:0	18:1	18:2	18:3	20:1	22:1	Other	Reference
1	Sunflower	30	0	6.08	3.26	16.93	73.73	0	0	0	0	[4]
2	Soybean	42	0	11.75	3.15	23.26	55.53	6.31	0	0	0	[4]
3	Jatropha	59	0	15.4	7	43.1	34.5	0	0	0	0	[31]
4	Taramira	35	0	10.2	1.6	22.8	6.4	11.9	6.4	40.8	0	[32]
5	Mustard	33	0	2	2.5	23.5	15.5	10	5	30.5	0	[32]
6	Safflower	28	0	7	2	13	78	0	0	0	0	[33]
7	Peanut	32	0	11	2	48	32	0	0	0	0	[33]
8	Cottonseed	30	1	22	3	19	54	1	0	0	0	[33]
9	Sesame	31	0	9	4	41	45	0	0	0	0	[33]
10	Rice bran	17	0	15	1.9	42.5	39.1	1.1	0.5	0.2	0	[33]
11	Linseed	34	0	3	7	21	16	53	0	0	0	[33]
12	Pongame	35	0	11.67	7.85	62.16	0.6	0.48	0.24	0	17	[33]
13	Castor	32	0	0.7	0.9	2.8	4.4	0.2	0	0	90.2	[4,34]
14	Canola	33	0	3.49	0.85	64.4	22.3	8.23	0	0	0	[33,35]

In 2005 hardly more than 2 acres were utilized for jatropha cultivation [36]. However, there on, private sector started developing nurseries for further cultivation. During 2006 more than 10,000 saplings were provided by nursery owners to various farmers in Sindh and Punjab for transplantation into the farms. In the year 2007, these nurseries provided around 50,000 saplings for transplantation to various farmers in Sindh and a few to counterparts in Balochistan [36]. However, due to hyped curiosity, awareness and possible economic gains in the cultivation of jatropha, farmers in Sindh showed more interest, and due to the large scale availability of saplings with the nurseries, in 2008, more than 200,000 saplings were provided by various nurseries in Sindh for such transplantation.

During 2008, Pakistan State Oil (PSO) too imported germination seeds for developing nursery and transplanted 20,000 saplings on their own farm [36]. At present they have around 10–20,000 more saplings for such transplantation [36,38].In addition, within the quarter of 2009, their nurseries near Karachi already had more than 200,000 saplings and were ready to provide more if required. Present and projected progress with the cultivation of jatropha, by the end of year 2014, is shown in Fig. 3 [36].

PSO has launched a pilot project based upon harnessing *Jatropha curcus* plants from its own farms for large scale biodiesel production [39]. The projected benefits for Pakistan have been envisaged as follows [39]:

- 6 million trees will be added for a greener environment;
- 500 farmers will be hired to manage the plantation on 5,000 acres;
- 24 million kg seeds will be produced per year from this plantation;
- 7.2 Million Litres of biodiesel (worth approximately PKR 345 million @ PKR 48/litre of petroleum diesel) will be produced per annum which is equivalent to 17 MT of biodiesel per day.

Other stakeholders such as Karachi's Forest Department together with Pakistan Army have successfully cultivated jatropha plants in various regions of Sindh [40]. So far, the Forest Department managed to cultivate 3000 plants on an experimental basis in Malir Cantonment in 2010. The jatropha seeds were supplied by PSO [36]. In addition, Pakistan Agricultural Research Council (PARC) and Canadian company, Kijani Energy are developing large scale cultivation of jatropha for biodiesel on marginal lands [41]. Kijani Energy invested about US $150 million in 2009, which has resulted in the utilization of 200,000 acres of land in Cholistan, Umerkot, Tharparker, Khairpur and Sangharfor the purposes of jatropha plantations [42].

The benefit of such activities can be manifold. Plantation of jatropha is likely to create at least one job for every acre of planted trees; the total impact on agricultural employment alone could be huge [36]. Biodiesel production cost will depend on the cost of procurement of seeds, scale of manufacturing, government policies related to taxation, utilization of by-products, seed cake and other jatropha waste residues. However, while considering the cost factor, it is essential to look at the rural employment generation, energy security, carbon trading issues, and savings of foreign exchange [36].

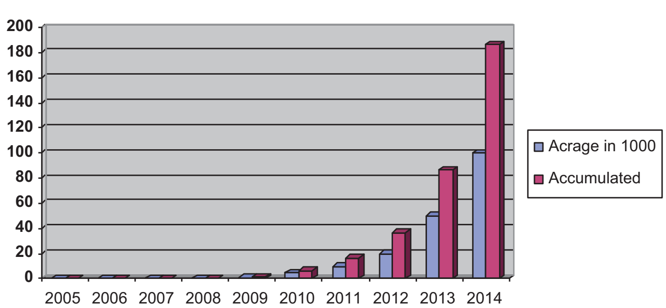

Fig. 3. Projected growth of PSO's Jatropha cultivation [36,38].

Overall employment will be generated from plantation, seed collection, oil extraction, biodiesel manufacturing, and localized distribution [36]. Employment generation from plantation and seed collection alone is estimated to be 40 man days/ha/ year.

4.1.2. Status of biodiesel research using indigenous jatropha oil

The jatropha curcas plant is a drought resistant crop that develops deep taproot shallow roots allowing it to resist and control soil erosion. The leaves are smooth, 4–6 lobed and 10–15 cm in length and width. It gives about 2–4 kg/seed/tree/year. In poor soils, the yields have been reported to be about 1 kg/seed/tree/year. The oil yields of jatropha curcas is reported to be 1590 kg/ha [43]. The major fatty acids in jatropha curcas seed oil are the oleic, linoleic, palmitic and stearic acids, and the general properties of the oils obtained from this plant are presented in Table 2.

The cost of production of biodiesel from jatropha will arguably vary from location to location due to labor charges, land acquisition and policies in place. However, Silitonga et al. [43] presented a strong case for biodiesel production from jatropha. On the basis of 500 workers working on a farmland of 1,500,000 ha an approximate amount of 2,250,000 L can be generated. Taking into account the labor cost applicable to the region of interest, the expected revenue can be computed. On the land use, it should be noted that jatropha costs almost nothing to grow, does not require expensive crop rotation or fertilizers. Several organizations in Pakistan have been involved in the production and testing of biodiesel from jatropha curcas oil. The main thrust behind the work has been a high oil content in the seeds (ca 30% to 40% [44]) as well as the presence of anti-nutritional chemicals in the oil that tend to make it inedible [45].

4.1.2.1. Universities results. Among the universities that reported results from the transesterification of jatropha curcas oil were University of Agriculture in Government College University, Faisalabad [40], Quaid-i-Azam University in Islamabad [33,45,46] and NED University in Karachi [31]. Besides that, PSO itself has worked with various other universities in Pakistan for the same purposes [39]. Faisalabad managed to obtain 94% yield of biodiesel from jatropha oil [47] whereas PSO claimed higher yields [39].

Table 2
Highlight of properties of Jatropha curcas oil [43].

Property	Parameter status	Remark
Kinematic viscosity	Very high	The kinematic viscosity of crude J. curcas oil can be reduced to about 82% after transesterification and amounts to be 4.8 mm^2/s using preheating, blending, ultrasonically assisted methanol transesterification and supercritical methanol transesterification.
Pour point	Low in comparison to edible oils biodiesel	It may be used in some four season's countries
Iodine value	High	Indicated higher unsaturation of fats
Flash point	Higher in comparison to diesel	Due to higher flash point, Jatropha oil has certain advantages over diesel such as greater safety during storage, handling and transport.

Table 3
Main properties of high speed diesel and indigenous jatropha bio diesel tested by Faisalabad [47] and PSO [48].

Parameters	High speed Diesel (PSO)	B10 (PSO)	B100 (PSO)	B100 (Faisalabad)	Test Method
Density at 20 °C g/cm^3 (lb/in^3)	0.83 (0.030)	0.8522	0.8816	0.88	ASTM D 1298
Kinematic Viscosity mm^2/s (in^2/s)	2.73 (0.0042)	4.19	4.38	4.8	ASTM D 445
Cetane index	46	53	47	NE	ASTM D 976
Flash point °C (K)	37 (310)	90	140	188	ASTM D 93
Calorific value Btu/lb	19528	19233	17162	NE	ASTM D 240

NE: Not evaluated.

Table 4
Cost of producing 1 l of biodiesel from different non-edible indigenous oils [49].

S. No.	Biodiesel	Cost per liter (PKR)
1	Jatropha	94.549
2	Castor	162.708
3	Taramira	277.004

1 USD = 91 PKR.

The fuel properties of jatropha oil biodiesel, evaluated by PSO and separately at Faisalabad, are shown in Table 3. The major difference between both fuels was the fact that Faisalabad's biodiesel had a higher flash point than PSO's counterpart. Although that meant a safer fuel for the former institution, it also resulted in the disadvantage of lower ignitability thereby reducing the value of the fuel. This may have been due to a more refined approach adopted by PSO in ensuring its product quality due to a higher sense of corporate responsibility [48].

NED University managed to test PSO's biodiesel in a single cylinder four stroke compression ignition engine (Rotronics) and found that its emissions profile was better than that of diesel, canola oil biodiesel and castor oil biodiesel [31]. The researchers at NED University also concluded that biodiesel from jatropha curcas seeds was cheaper to produce than indigenous castor and taramira oil biodiesels (Table 4) [49].

4.1.2.2. Results from Pakistan state oil. PSO has very successfully converted jatropha oil from its own plantations to biodiesel using a state-of-the-art transesterification unit [39]. Engine performance and emissions testing of PSO's B10 were conducted by NED University recently [31]. The results clearly show that jatropha biodiesel has least impact upon the environment in comparison to other indigenous biodiesel fuels as well as mineral diesel but its engine performance is marginally worse than its mineral counterpart. This is because of its lower calorific value than mineral diesel [31]. This issue can be overcome if further research is conducted by Pakistani institutions to increase the calorific value of jatropha oil biodiesel.

4.1.2.3. Status of biodiesel research using indigenous pongame oil

Pongame (also known as Karanj) is a plant that grows in humid & sub tropical environments and is cultivated in those areas having annual rainfall ranging between 500 and 2500 mm in its natural habitat [50]. Pongame is a potential raw material for biodiesel production in Pakistan [51]. It is a tree of 12–15 m height, with spread branches. The seeds can yield up to 35% of oil [51]. Since this plant can withstand salinity, water logging and slight frost and also it can grow on different soil types, it can be grown and planted in major parts of Pakistan as the country is plagued with problems of barren and uncultivated lands [51]. Some of the advantages of pongame are: a higher recovery and quality of oil than other crops, no direct competition with food crops as it is a non-edible source of fuel, and no direct competition with existing farmland as it can be grown on degraded and marginal lands. As a legume it is also able to fix its own nitrogen from the soil, minimizing the need for added fertilizers [52].

Quaid-e-Azam University (QAU) converted pongame oil to biodiesel successfully by means of catalytic transesterification using NaOH as the catalyst [50,52]. A maximum conversion of crude Pongame oil to biodiesel of 90% was obtained. A similar, but more successful attempt was also made by separate workers in the NED University in Karachi (unreported). The fuel properties of the biodiesel samples produced at both institutions are given in Table 5. The fuel produced at NED had better properties than the one produced at QAU. Also, its flash point was higher, indicating that it was safer to store. However, its ignitibility was less than the fuel produced at QAU.

A performance trial for biodiesel was carried out at the test ground for internal combustion engines in the engines laboratory of QAU and a road test run of a Toyota car (2D) belonging to the Alternative Energy Development Board (AEDB), Islamabad was performed successfully [53,54]. However, no results were reported in terms of engine emissions or engine performance parameters. It appeared that the only CI engine results reported from Pakistan were from UET, Lahore (please see Section 4.3 for full details and references).Pongame biodiesel was found to give lesser emissions of priority pollutants than jatropha and had comparable brake power and torque at same engine speeds with jatropha. The key again would be to improve the calorific value of the fuel such that its performance can be at par with mineral diesel fuel.

4.2. Harnessing of indigenous resources for biodiesel production—AEDB's pioneering work

4.2.1. Alternative energy development board's contribution

The Government of Pakistan created the Alternative Energy Development Board (AEDB) in 2003, with the aim of promoting and facilitating the harnessing of renewable energy resources in the country [8]. Draft for the policy of development of renewable energy was issued in 2006. AEDB has been able to motivate different vendors and Universities to start research work on biodiesel and other renewable energy resources from that time onwards [55–57]. The AEDB has been tasked by the Government to promote biodiesel through a National awareness program.The AEDB has also been cultivating jatropha in Karachi with the help of parties and stakeholders [55].

4.2.2. Collaboration with local Universities

During 2009, AEDB's initial research on biodiesel resources in Pakistan was successfully completed. The potential oil resources identified include Pongamia pinnata, rapeseed and castor bean [57].The organization successfully demonstrated B10 and B20 biodiesel fuels from these indigenous resources in diesel run vehicles. It also established a research lab at QAU and a fuel testing lab at University of Engineering and Technology, Taxila

Table 5
A comparison of fuel properties obtained for pongame oil biodiesel at two different Universities in Pakistan (unreported results from NED University shown here).

Parameters	ASTM Test Method	ASTM Limits	HSD	Pongame B100 (NED)	Pongame B100 [51]
Density @ 15 °C (g/cm^3)	ASTM D1298	0.875–0.900	0.85	0.88	0.92
Viscosity @ 40 °C (cSt)	ASTM D445	1.9–6.0	2.8	3.9	7.53
Flash point (°C)	ASTM D93	93 °C, Min	68	152	90
Sulphur content (%)	ASTM D5453	0.0015, Max.	2.4	0.0010	0.0084
Cetane index	ASTM D613	47, Min	46.2	58	53
Water and sediment (vol%)	ASTM D2709	0.050, Max.	0.02	0.005	NA
Total acid value (mg KOH/g)	ASTM D974	0.50, Max.	N/A	0.20	NA
Oxidation stability (h)	EN 14112	6, Min.	8	7	NA

[57]. The electrification of a village in interior of Sindh province (Goth Umar Din) followed suit. For this a close policy was observed, where the producer of alternative energy was the user as well [58]. The villagers were growing the required seeds for the vegetable oil and producing biodiesel through transesterification and also operated the installed generator set to generate electricity for their village.

4.2.3. Commercial ventures

Commercial production of biodiesel was initiated by Clean Power (Pvt.) Ltd. along with AEDB by setting up a 400 l/day refinery [59,60].This project utilized multiple options in phases including growing of crops on waste lands, plantation of Pongamia and Jatropha trees and use of waste vegetable oils. Clean Power also worked with Pakistan Railways to plant pongame seeds in various parts of the country [61].

4.2.4. Formulation of biodiesel policy recommendation

AEDB formulated a Biodiesel policy recommendation in 2008 which included the following major proposals [58]:

a. Introduction of 5% Biodiesel blended fuel by the year 2015 and 10% by 2025 in Pakistan.
b. Oil marketing companies were to purchase B (1 0 0) Biodiesel from Biodiesel manufactures and sell the Biodiesel blended fuel (B-5) at their points of sale.
c. Oil gas regulatory authority was to regulate the pricing mechanism of various blends of Biodiesel.
d. All imprinted plants machinery, equipment and specific items used in the production of Biodiesel were supposed to be exempted from customs duty, income tax and sales tax.

After the approval of Policy Recommendations for the use of Biodiesel as an alternative fuel, SRO 474 (I)/2008 for the exemption of taxes and duties on Biodiesel related equipment, machinery and other specific items was issued by the Federal Board of Revenue (FBR), Government of Pakistan [55]. In response to that, AEDB got approval for setting up a 10,000 t/annum biodiesel production facility as part of the Government's feasibility study for initiating a B5 nationwide program by 2015. The other benefit of the aforementioned policy was the commencement of Pakistan's first ever commercial biodiesel production facility (amounting to 18,000 t/annum of fuel) under the auspices of M/s Eco-Friendly Fuels Private Ltd. and AEDB [55].

4.3. University research results

Several Universities in Pakistan have been performing high quality research on biodiesel since the inception of AEDB in 2003. Their research results are discussed in this section.

4.3.1. Biodiesel production

The technology of transesterification was first developed and tested at Sir Syed University of Engineering and Technology Karachi [62]. The total capacity for production of Biodiesel was 100 l/batch in two hours [62].On full scale it could produce up to 400 l of biodiesel per day, which a 200 kW generator could run for 8 h using B100 fuel [63].

Transesterification of chicken and mutton fats was carried out under different experimental conditions by using acid and base catalysis for the production of fatty acid methyl esters in Faisalabad [64]. Biodiesel produced using acid catalysis resulted in higher yield in comparison to base catalysis. Different experimental parameters such as amount of catalyst, temperature and time affected the production of biodiesel. Optimum amount of H_2SO_4, temperature and time were 1.25 g (on fat weight basis), 50 °C and 24 h for chicken fat, and 2.5 g (on fat weight basis), 60 °C and 24 h for mutton fat. Results of the study clearly demonstrated that the use of chicken and mutton fats was suitable as low cost feed stocks for biodiesel production [64]. However, further work in terms of scaling up the technology towards commercialization has not been reported.

A Pakistani scientist from the National Center for Physics at the Quaid-e-Azam University in Islamabad has successfully invented a nano catalyst for production of biodiesel with the help of spent tea leaves for the first time in the world, opening up new avenues for alternative environment friendly energy resources. The nano particles help produce 560 ml of biodiesel from 1 kg of used tea leaves at a conversion of 41% [65].

Quaid-e-Awam University (QUEST) at Nawabshah has also been involved in the cultivation of jatropha plantations in a similar manner to WWF Pakistan in coordination with Qarshi Industries [66]. However, no reports on any biodiesel production at QUEST are available in the open literature as yet.

The Department of Mechanical Engineering at the University of Engineering and Technology (UET), Lahore had performed several projects on the evaluation of emissions from diesel engines fueled with sunflower and soyabean oil biodiesel fuels [67–74]. The results of their work have been discussed in brief in the next section.

The Institute of Chemistry at Punjab University has been converting molasses from sugar industry wastes into biodiesel fuel [75]. Their technology involved the fermentation of molasses into ethanol which was then used as a reagent in the transesterification process [76]. No scientific papers reporting outcomes of this investigation were available in the open literature.

The National University of Science and Technology (NUST) in Islamabad have been developing biodiesel from jatropha curcas oil recently [77]. The oil has been obtained from plants growing in NUST's own model farm that covers an area of 15 acres for jatropha cultivation. Half a million jatropha trees have already been planted and there are plans to plant a total of 4–5 million trees this year [77]. However, no scientific papers are available detailing the results obtained by NUST.

NED University of Engineering and Technology in Karachi has also been conducting a focused research program for the conversion of non-edible oil from indigenous vegetation into biodiesel fuel. The first raw material that was successfully converted to biodiesel was castor bean oil [4,34]. Due to high viscosity of the oil, an esterification method recommended by Marchetti et al. [78] was adapted for the purposes. Despite that a maximum yield of 85% was reported by the authors. Hence, it was concluded that to consider castor as a long run candidate for biodiesel production in Pakistan may not be very practical unless an economic enzymatic process is developed for reducing the high viscosity of the castor oil [4].

The oil of *E. sativa* L. or taramira plant that grows very commonly on barren lands of India and Pakistan was also converted to biodiesel successfully at NED [32]. The transesterification procedure for preparing jatropha oil biodiesel was followed as outlined in the literature [79,80]. The biodiesel was tested against ASTM D 6751 standard and found to comply with all parameters except having a lower flash point than expected. This issue was attributed to missing out the refining procedure of the crude oil prior to transesterification [32]. However, it was expected that the cost of producing biodiesel from this raw material would be high due to the high price of commercial taramira oil itself.

NED University has also been cultivating jatropha plants in their own nursery [81]. Although no seeds were extracted for transesterification purposes, NED collaborated with PSO briefly to run some engine emissions testing of jatropha oil in the compression ignition engine as detailed in the literature [31]. In addition, NED initiated a national biodiesel seminar in which PSO demonstrated their van which was fueled with jatropha B10 [81].

The University of Agriculture, Faisalabad (in collaboration with other institutes in Pakistan and USA) successfully produced biodiesel from cottonseed oil, rapeseed oil, moringaoleifera oil, rice bran oil, safflower oil and sunflower oil [82–87]. In all cases, the biodiesel fuels produced met the respective ASTM D 6751 standard and optimum means of transesterification was established successfully. However, rice bran oil could only be converted to 83% yield [85], almost similar to the result obtained in the esterification of castor bean oil [4]. It is pertinent to mention here that Faisalabad focused mainly on edible vegetable oils and animal fats for biodiesel production. This meant that the issue of food against fuel crisis could crop up significantly if such cash crops were recommended for a nationwide biodiesel production in the future [81].

Last but not least, QAU in Islamabad have also been working on the transesterification of several indigenous oils to biodiesel [88–95]. A variety of indigenous raw materials such as cottonseed, rocket seed, peanut, rice bran and inedible neem tree oils have been transesterified and analyzed. Based upon certain optimum parameters (such as oil to methanol ratio, catalyst amount and others) it is possible to produce about 92% of methyl esters (biodiesel) from the vegetable oil, which surprisingly meet all ASTM D 6751 parameters. This result is in contrast to those reported by NED University, where the researchers took care to ensure that biodiesel yield (measured by methyl ester content) reached a minimum of 97% prior to subjecting it to ASTM test procedures [35,96].

A separate investigation by QAU on the effect of plant growth regulators on the oil yield and acidic value of indigenous linseed oil was published recently [97]. The growth regulators may have had some useful influence in improving the oil quality of linseed (in a similar manner as for soyabean [98]) but upon transesterification, ester contents were below the ASTM minimum recommended value. Besides, linseed may not have been a very good candidate for Pakistan because of its nutritional value.

4.3.2. Biodiesel testing in engines

NED University's researchers first converted indigenous canola oil to biodiesel [99] and performed engine emissions testing of the fuel using a Chinese made single cylinder diesel engine [35]. In general, major environmental parameters were found to be lower for blends of biodiesel with mineral diesel in comparison to pure mineral diesel itself. NO_X emissions were higher as expected due to greater oxygen content in the molecules of biodiesel. Overall, in this study, it was found that biodiesel blended between 20% and 25% showed optimum performance in terms of environmental emissions (i.e., giving least CO, SO_2 and particulate matter emissions) and can be recommended as a gradual replacement for petroleum diesel subject to the use of lower cost feedstock for preparing this clean fuel [35].

Castor oil based biodiesel was then blended to 10% quantity by volume with petroleum diesel and tested in a Rotronics double cylinder compression ignition engine [34]. The blended fuel was found to give lower environmental emissions in most accounts except for higher CO_2 and NO_X. In addition, three engine performance parameters were assessed, which were engine brake power, engine torque and exhaust temperature. In the first two cases, blended biodiesel fuel gave lower figures than pure mineral diesel due to lower calorific value. However, its higher flash point resulted in higher engine exhaust temperatures than pure mineral diesel. Overall, in terms of engine performance, castor oil biodiesel (from non-edible oil of castor bean—growing on marginal lands of Pakistan) fared better in comparison to canola oil biodiesel (from expensive edible oil) [34].

The results of castor bean biodiesel were compared to engine testing parameters of jatropha oil biodiesel supplied by PSO [31]. Comparison was done for emissions and engine performance parameters at blends of 10% by volume of biodiesel with mineral diesel fuel. The performance of engine parameters showed that the castor oil based biodiesel gave the best results. Economic feasibility for biodiesel production was carried out based on available data on cultivation of necessary plants on marginal lands. This economic analysis also included the value of by-products which would be available during the chemical process for the production of biodiesel. It was found that jatropha biodiesel could be produced at a comparable cost to mineral diesel; however, castor biodiesel required substantial subsidies or mass cultivation of plants on marginal lands to enable it to compete economically with mineral diesel [4]. The same was concluded when 10% blends of *E. sativa* L. biodiesel were subjected to similar engine testing and economic analysis as reported in a recent publication [49]. Due to the high cost of the *E. sativa* L. oil in Pakistan, the economics of producing biodiesel from it disqualifies it as a suitable indigenous resource that could benefit Pakistan in the near future unless fossil fuel prices reach the sky.

Nevertheless, the recent work of Chakrabarti et al. established one positive point going in favor of *E. sativa* L. biodiesel [49]. It is definitely more environment friendly than castor, canola and jatropha oil biodiesel fuels. This result was also confirmed by an independent group of researchers in China [100].

The work of QAU in terms of engine testing appeared to be better than those reported by NED. QAU reported that engine performance parameters in terms of fuel consumption, efficiency, and power outputs were similar for mineral diesel and biodiesel blends [91]. No obvious change in engine power was observed when using 100% biodiesel in the diesel engine except that engine emissions were much lower. Based upon such results, QAU recently conducted an investigation at Sihala whereby a railway engine was successfully run with the help of biodiesel [101]. From this test, the scientists concluded that bio-diesel had no negative effects on the 'health' of the engine and it was quite parallel in terms of performance to mineral diesel.

Results reported by UET Lahore were different to the ones obtained by NED University. UET found that biodiesel gave higher hydrocarbon emissions in comparison to mineral diesel fuel [67–74]. The results obtained by UET were for 100% soybean biodiesel fuel (B100) whereas NED reported results for 20% blends. Other international researchers also reported conflicting results. For example, Cardone et al. [102] found increasing hydrocarbon emissions for biodiesel in comparison to mineral diesel whereas Peng et al. [103] reported the reverse result. Due to that, Pakistani and Chinese researchers have recommended further research for a better understanding on the formation of carbonyl compounds from biodiesel fuel [104].

4.4. Commercial research results

Brief descriptions regarding commercial plans for biodiesel production in Pakistan has already been reported in Sections 3.1 and 3.2. As mentioned earlier, mainly Clean Power and AEDB have been pushing to commercialize biodiesel distribution throughout the nation. The main focus appears to be mainly revolving around jatropha and pongame oil biodiesel fuels as other indigenous vegetable oils have yet to show much economic promise in Pakistan.

The first step taken in 2006 was by Clean Power with the backing of AEDB. They phased out four main objectives for a pilot project leading to commercialization [60]:

- Development of model B10 filling station.
- Develop confidence amongst users of biodiesel.
- Develop a strong awareness on the biodiesel manufacturing and purification technology.
- Develop an efficient supply chain management program.

5. The possibility of harnessing indigenous algae for biodiesel production

Biodiesel production from the lipase of algal cells is not a new concept. It has been thoroughly reviewed by several research groups that have discussed its challenges and opportunities for the global energy market [105–110]. Several organizations in Pakistan have used this idea to do preliminary research on algal biodiesel production building upon initial screening studies of several indigenous species [111]. Two of them are in Karachi, one being the Pakistan Council for Scientific and Industrial Research [112] and the other being the Department of Biochemistry, University of Karachi [113]. Unfortunately, the oil yield of the algae grown in the labs of both institutions wasn't satisfactory to meet the standard described by Chisti [109]. However, research is still underway.

A Pakistani researcher at Mie University of Japan has recently claimed that the nation could benefit by harnessing its 27–28 million acre saline lands for algal farming [114]. The same fact has also been confirmed by researchers in Malaysia [115].Considering that about 40% of algal biomass consists of lipids that can be extracted of oil for producing biodiesel, the researcher mentioned that Pakistan should follow the example of other countries who are running similar projects of re-claiming saline lands and producing sustainable bio fuels. He also remarked that the Pakistan Technology Board, an organization of Ministry of Science and Technology responsible to identify and promote key technologies in Pakistan, had already taken some initiatives to promote innovative research approaches towards bio fuel production [114].

Other researchers have identified four strains of algae suitable for cultivation in Pakistan's deserts [116]:

- Haematococcuspluvialis.
- Microcoleusvaginatus.
- Chlamydomonasperigranulata.
- Synechocystis.

So far there has been plenty of clamor regarding commencement of a full scale algal biodiesel project in Pakistan but very little has been done so far. No commercial reports are available in the scanty literature either. One of the main reasons may be due to the high costs associated with farming algae on a large scale as reported in a recent article in Dawn [117]. If a cost effective method of producing algae on both saline lands as well as sewage networks is developed, algal biodiesel could become a major success in Pakistan.

6. Possibility of re-using waste vegetable oil and animal fat for biodiesel

The used domestic waste oils and spent animal fats are arguably a safe and cost effective source of useable fuel [12]. Their conversion offers the merits of greenhouse gas emission (GHG), potentials for enhancing fuel diversification and a qualitatively comparable energy to fossil diesel fuels. Considering the fact that the average suspended particulate matters in Pakistan are about 6.4 times higher than WHO guidelines and 3.8 times higher than Japanese standards [118], the exploitation of waste oils for biodiesel production would benefit the nation considerably.

The Biomass Conversion Research Group at Comsats Institute of Information Technology has developed technology for producing biodiesel from waste vegetable oil (WVO) available indigenously in Pakistan [119]. They have estimated that an average of 240 million liters of WVO is produced in Pakistan per annum. Based upon their own yield of 85% in their laboratories, Comsats have estimated that about 155 million liters of biodiesel can be produced per year in the country [119]. To demonstrate by example, Comsats have already tested their WVO biodiesel fuel in a 5 KVA diesel generator successfully. They now have plans to run Comsats vehicles using this fuel and are thus setting up a production plant for the purposes [119].

7. Conclusion

From the reviewed articles and publications, it is vividly demonstrated that the energy requirement in Pakistan can be achieved and the looming energy crisis averted. However, to attain this, coherent biodiesel policies by the Government need to be enforced with greater focus devoted to supporting the initial local research efforts and harnessing used domestic waste oils and spent animal fats. From the former feedstock, an annual figure of 155 million liters can be produced. On the latter source, analysis shows that a cheaper alternative to complement the bioenergetics crops exploitation avails. In addition, AEDB's and PSO's initiatives to engage various universities throughout the nation should be harnessed so that effective solutions can be found in meeting the requirement of blending 10% of biodiesel with mineral diesel by the year 2025.This is because all major Pakistani research institutions and universities have reported that the biodiesel produced have met the ASTM D 6751 standard.

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